BRNO UNIVERSITY OF TECHNOLOGY
VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION
FAKULTA ELEKTROTECHNIKY
A KOMUNIKAČNÍCH TECHNOLOGIÍ

DEPARTMENT OF FOREIGN LANGUAGES
ÚSTAV JAZYKŮ

CURRENT TRENDS IN THE AIRLINE INDUSTRY
SOUČASNÉ TRENDY V OBLASTI LETECKÉHO PRŮMYSLU

BACHELOR'S THESIS
BAKALÁŘSKÁ PRÁCE

AUTHOR — Filip Štourač
AUTOR PRÁCE

SUPERVISOR — Mgr. Šárka Rujbrová
VEDOUCÍ PRÁCE

BRNO 2021

VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ
FAKULTA ELEKTROTECHNIKY A KOMUNIKAČNÍCH TECHNOLOGIÍ

Bakalářská práce

bakalářský studijní obor **Angličtina v elektrotechnice a informatice**

Ústav jazyků

Student: Filip Štourač ***ID:*** 203166
Ročník: 3 ***Akademický rok:*** 2020/21

NÁZEV TÉMATU:

Současné trendy v oblasti leteckého průmyslu

POKYNY PRO VYPRACOVÁNÍ:

Popište nejnovější technologie a strategie, jež se v současné době používají v oblasti leteckého průmyslu. Zaměřte se nejen na současný stav, ale i na předpokládaný budoucí vývoj v této oblasti.

DOPORUČENÁ LITERATURA:

O'Connell, J. F. & Williams, G. (2011). Air Transport in the 21st Century: Key Strategic Developments. NewYork: Routledge

Eriksson, S. & Steenhuis, H. J. (2016). The Global Commercial Aviation Industry. New York: Routledge

Belaboba, P., Odoni, A. & Barnhart, C. (Eds.). (2009). Chichester: John Wiley & Sons Ltd.

Doganis, R. (2006). The Airline Business. New York: Psychology Press

Termín zadání: 31.1.2021 ***Termín odevzdání:*** 31.5.2021

Vedoucí práce: Mgr. Šárka Rujbrová

doc. PhDr. Milena Krhutová, Ph.D.
předseda oborové rady

Abstract

The goal of this bachelor thesis is to describe current technological trends in the airline industry and outline the expected future development in the aviation sector. The introduction starts with brief overview of aviation history followed by short depiction of a modern age aircraft. The next chapter deals with green technology and sustainability of aviation with focus on 3D printing, alternative jet fuel and two types of modern engines- Leap engine by CFM and geared turbofan by Pratt&Whitney. Third chapter about safety technology covers Ground Proximity Warning System and runway sensors. The following chapter focuses on current changes in maintenance technology regarding the growth of Internet of Things. In the last chapter, the reader is introduced to the expected future development of aviation.

Keywords

Aviation, technology, sustainability, safety, maintenance, future.

Abstrakt

Cílem této bakalářské práce je popsat současné trendy v leteckém průmyslu a nastínit předpokládaný budoucí vývoj v této oblasti. Úvod práce začíná stručným shrnutím historie letectví, které je následováno krátkým popisem současného leteckého průmyslu. Další kapitola se zabývá ekologickými technologiemi a udržitelností letectví se zaměřením na 3D tisk, ekologické letecké palivo a 2 rozdílné typy proudového motoru: LEAP od společnosti CFM a Geared turbofan od Pratt&Whitney. Následuje třetí kapitolou s přehledem bezpečnostních technologií ve které je popsán systém GPWS a senzory snímající kontaminaci ranveje. Další kapitola se pak zabývá aktuálními změnami v technologiích údržby, způsobenými rostoucím trendem Internetu věcí. Poslední kapitola čtenáři odhaluje předpokládaný budoucí vývoj leteckého průmyslu.

Klíčová slova

Letectví, technologie, udržitelnost, bezpečnost, údržba, budoucnost.

Bibliographic citation

ŠTOURAČ, Filip. Současné trendy v oblasti leteckého průmyslu [online]. Brno, 2021 [cit. 2021-05-31]. Dostupné z: https://www.vutbr.cz/studenti/zav-prace/detail/134530. Bakalářská práce. Vysoké učení technické v Brně, Fakulta elektrotechniky a komunikačních technologií, Ústav jazyků. Vedoucí práce Šárka Rujbrová.

Prohlášení

Prohlašuji, že svou bakalářskou práci na téma Současné trendy v oblasti leteckého průmyslu jsem vypracoval samostatně pod vedením vedoucího bakalářské práce a s použitím odborné literatury a dalších informačních zdrojů, které jsou všechny citovány v práci a uvedeny v seznamu literatury na konci práce. Jako autor uvedené bakalářské práce dále prohlašuji, že v souvislosti s vytvořením této bakalářské práce jsem neporušil autorská práva třetích osob, zejména jsem nezasáhl nedovoleným způsobem do cizích autorských práv osobnostních a jsem si plně vědom následků porušení ustanovení § 11 a následujících autorského zákona č. 121/2000 Sb., včetně možných trestněprávních důsledků vyplývajících z ustanovení § 152 trestního zákona č. 140/1961 Sb.

V Brně dne……….. ………………..

Filip Štourač

Table of content

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

ICAO - International Civil Aviation Organization

TTBW - Transonic Truss-Braced Wing

LEAP – Leading Edge Aviation Propulsion

IoT – Internet of Things

IIoT – Industrial Internet of Things

AM – Additive Manufacturing

SM – Subtractive Manufacturing

CORSIA - Carbon Offsetting and Reduction Scheme for International Aviation

SAF – Sustainable Aviation Fuel

RPM – Revolutions Per Minute

CFIT – Controlled Flight Into Terrain

GPWS - Ground Proximity Warning System

EGPWS – Enhanced Ground Proximity Warning System

GRF – Global Reporting Format

MRO – Maintenance, Repair and Operations

FAA - Federal Aviation Administration

EASA - European Union Aviation Safety Agency

Introduction

On December 17, 1903, Wright brothers successfully completed the first engine – powered flight. The flyer – as their airplane was named – stayed airborne for 59 seconds, covering the distance of 260 meters which was unheard of at that time. It was constructed from wooden frame covered by fabric for better aerodynamic properties and powered by 12.5 horsepower engine. Featuring several innovations, such as use of cast aluminium block or the use of rotating propellers to generate thrust, Flyer laid the foundations for modern day aviation.

Wright brothers started a worldwide lust for improvement of aviation technology which escalated even more by the vision of using planes for military purposes. By the end of twenties, British Supermarine S.6 already reached the speeds over 528 km/h and became predecessor of the famous Spitfire fighter aircraft. The introduction of first airlines in 1919 and following innovations led by the National Advisory Committee for Aeronautics (NACA – forerunner of NASA) opened the benefits of aviation to the upper class, slowly forming the sector of commercial aviation. The airplane which really brought flight to the masses was Douglas DC – 3 introduced in 1935 of which more than 13 000 were built over its 10 years production period. The aircraft was praised by the pilots for its forgiveness of errors and by the passengers for its trustworthy performance and luxury services onboard. It was a true marvel of its age proven by the fact that an estimated 172 exemplars according to Michael Prophet are still in service today, used by the military or to transport passengers and cargo in remote locations.

Figure 1: Douglas DC – 3 (*Jim Koepnick via* Vintage Airplane, September 2006.)

Modern day aircrafts are however very different machines. Since the debut of jet engine on commercial aircraft in the 50s, silhouette of an aircraft undergone only slight alteration and rather than changing a working concept, manufacturers started improving the technologies. Refined engines with better fuel economy allowed for lowering the ticket prices and as consequence, people started taking leisure flights as the preferred form of holiday transport. The increased interest provided more cashflow to the airlines and the number of aircraft grew substantially together with their size.

Nowadays, Airbus A380, a new generation widebody aircraft can accommodate more than 800 passengers in full economy configuration and allows for a maximum take-off weight of 575 tonnes. Such giant aircrafts are however not so sought after as they once were with the interest turning towards smaller, more cost-effective aircrafts with lower carbon footprint. As the worldwide global warming awareness grew over the last few decades, sustainability became driving factor of the industry.

1 CO2 reduction technology

In year 2019, humankind produced over 43 billion tonnes of CO2. From this unimaginable number, aviation industry accounts just for 915 million, which is roughly 2.1 %, however with 5.5% annual increase in emissions per passenger - kilometre, aviation is the fastest growing producer of greenhouse gas emissions. To provide a more accurate idea about the number of emissions produced by aviation, lets imagine Boeing 737 – 400 with average number of people onboard performing a single flight from Brno to Madrid. This flight with length of 1857 km produces 213.5 kg of CO2 per passenger which is comparable with the amount of CO2 produced by lighting an average Czech household for a year. Although these numbers are quite alarming considering the subsiding carbon budget of the Earth, strict measures to prevent the increasing carbon footprint of aviation are being taken, mainly by International Civil Aviation Organization (ICAO). ICAO separates emission – reduction related initiatives into three sectors incorporated in their tracker tool system - Technology, Operations and Sustainable Aviation Fuels. The technology tracker is categorized into four groups according to the classification below.

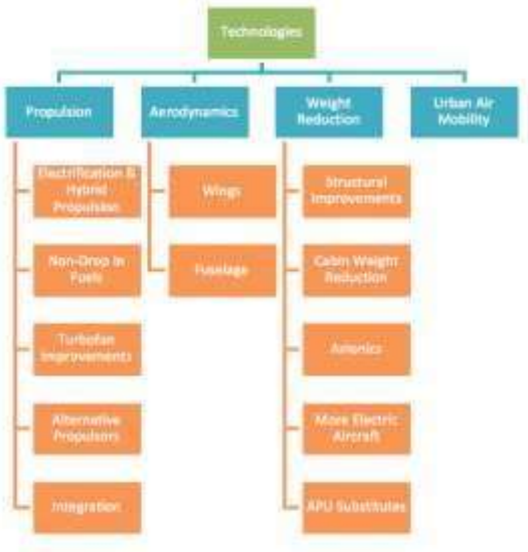

Figure 2: CO2 reduction technology tracker division (ICAO, n.d.)

The main focus of the industry is to standardize hybrid propulsion or, even better, full electrification of aircrafts. This goal is partly driven by success of electrification in other parts of transport sector, such as automotive or rail industry, combined with undeniable economic and ecological advantages of the solution. However, with current technology it is impossible to produce batteries with enough energy density to achieve desirable power to weight ratio and for that reason, full electric aircrafts are estimated to be in service no sooner than 2040s. Current trends are more oriented towards aerodynamics, weight reduction or jet engine improvements.

1.1 3D printed parts

"3D printing or additive manufacturing is a process of making three dimensional solid objects from a digital file" (What is 3D printing?, n.d.). The printer adds material layer by layer until the object is finished. In its beginnings, it was thought that this technology, originally printing just from polymers, is only suitable for faster creation of prototype models, however as the technology matured, its true potential became apparent. Currently, the palette of 'printable' materials is immense and ranges from chocolate to steel. It was the possibility of using metals and metal alloys for 3D printing which brought the technology under the radar of the industry as the use of additive manufacturing have numerous benefits.

While subtractive manufacturing is well established in all sectors of the industry, the technique has high material consumption since an object is machined from a solid piece of metal by milling the extra material away. In case of additive manufacturing, the volume of used material roughly equals the volume of the final product. However, as AM uses metal in powder form, the material undergoes the process of atomisation in which it is melted and transformed into powder by gas or plasma. Production of the metal powder is quite complex and energy consuming, but the same applies to the milling process used in SM. In the end, it is the complexity of the desired component which decides in favour of one or the other. Ragged parts are more suitable for AM since SM would produce too much waste, but milling process is still competent for production of simpler designs.

Best example of AM technology adoption in aviation is a mass production of 3D printed fuel nozzles by GE aviation for the LEAP engine. The production site established in 2015 pioneered high volume AM production in aviation sector with milestone of 30 000 3D printed fuel nozzles reached in 2018. A fuel nozzle is a component which sprays jet fuel into the combustor with high precision as any inconsistency in the spray pattern could shift the combustion flame closer to the side of the combustor resulting in overheating and possible fail of the component. For this reason, geometry of this part is relatively complex and manufacturing process must be performed with high precision. To achieve this by SM, 20 parts were milled separately and then welded together. Use of AM allowed combining these parts into 25% lighter and 5 times more durable single unit with shorter production time and lower cost.

Figure 3: 3D printed fuel nozzle for the LEAP engine (GE additive, 2018)

Since its first certification for commercial flight in 2015, AM simplified manufacturing of variety of component design which were virtually impossible to make using conventional methods and therefore made a pathway for more creative design approaches while also providing less time consuming and more cost-effective way of bringing such designs into production. With further incorporation of the technology, aircraft manufacturers (Boeing) hope to achieve from 2 to 3 million dollars savings per aircraft production and additional benefits during a lifetime of a plane as lighter parts contribute to fuel savings. According to Rolf Steinegger, reduction in weight by one kg saves ~ 0.02 to 0.03 kg of fuel per 1’000 km. These savings might seem negligible, but a commercial aircraft is built to fly millions of kms in its lifetime, so these savings add up.

1.2 Alternative jet fuel

Even though wide variety of alternative propellants including hydrogen, compressed natural gas or diesel was already tried and tested in the history of aviation, none of these options found much success in the long term since they did not offer desirable levels of safety or efficiency. While these options are widely viable in car sector, applicability in aviation have more to overcome due to higher safety and performance requirements.

Jet fuel used in commercial aviation is kerosene - based, high - energy - density fuel with few additives, preventing fuel freeze, uncontrolled ignition or forming of deposits. Being a fossil fuel, its amount is not infinite and with lower availability in the future, the prices will grow rapidly. Another issue is the number of emissions which are produced from production and burn of this fuel. For these reasons, development of renewable and sustainable alternative is addressed globally, but is still in first phases since the feasibility of sustainable jet fuel (SAF) depends on many factors. Current jet fuel standards commit any new fuel to provide compatibility with current aircraft technology as the finances and time needed for aircraft changes would offset the benefits of lower running costs. Blends of classic fuel and sustainable fuel which keep the kerosene properties, so called drop-in fuels, are therefore the only solution feasible in a near future. To maintain the kerosene characteristics and to suit the standards, jet fuel can contain up to 50% renewable hydrocarbon biofuel which can be produced from wide array of feedstock including industrial wastes, fats, sugars, algae, and biomass.

Until now, 7 production pathways of SAF have been certified with many more emerging technologies in testing process. SAF produced from biomass achieves the highest reduction of emissions since the CO2 generated during combustion is absorbed by the plants from which the fuel is produced, in addition different sources of biomass can be grown and harvested all around the world which contrasts with narrower accessibility of crude oil. If all savings during the production process are considered, SAF has potential to achieve carbon neutral growth of aviation with 63% life cycle emission savings (ICAO, 2016). Further, normalization of SAF could offer new work opportunities in developing countries as distribution of feedstock such as residual waste is high in these areas. In conclusion, with the wide range of feedstock which can be converted into fuel and with working manufacturing processes, SAF is one of the most promising paths for reduction of aviation emissions. However as standard jet fuel is well established and cheap to produce, SAF needs global support for further standardization of the technology to become competent.

Recently, things are gaining momentum with Munich Airport (2021) stating that "green kerosene will be available to refuel aircraft at the airport from 1st June 2021 after thorough technical testing. This means that sustainable aviation fuels (SAF) can now be delivered, stored and refuelled at the airport, provided they meet the relevant quality specifications for Jet-A1 aviation fuel."

1.3 Leap engine

Propulsion system of an aircraft is arguably its most important part. The main task of propulsion is to generate thrust to overcome the drag of an aircraft and create enough excess thrust to accelerate the aircraft. It was the turbofan engine which achieved this task with lower fuel burn and therefore allowed to cover greater distances. Since its first appearance in the 50s, turbofan undergone many improvements, the most significant being the reduction of engine core size, which allowed for higher bypass of air through the engine. As a result, the fuel consumption was lowered by 40%. Nowadays, advancements in materials and technology allow for further improvements which were unobtainable even few years ago.

LEAP engine manufactured by CFM international is a prime example of this development. Mounted to Boeing 737 MAX with slight changes to the airframe improving aerodynamics over classic 737, it accounts for most of 737 MAX 15% lower fuel consumption. In addition, NOx emissions were decreased by 50% and noise levels by 75% over other advanced turbofans. The engine utilizes 18 3-D woven carbon fiber composite fan blades with titanium leading edges for greater impact resistance. 3-D woven method prevents delamination and provides improved vibration damping for longer lifetime together with lower production costs over solid composites. This material is further used for fan casing to achieve a total of 500 kg savings per aircraft. Other improvements boosting the fuel economy include high bypass ratio of 11:1 achieved by larger fan diameter. To not overload the engine, high pressure turbine is operating at higher temperatures and the air is compressed 22x at the exit of the compressor which requires the use of ceramic coatings to withstand these conditions. Even though the engine uses all the above-mentioned technologies, the maintenance costs are said to be lower or in line with their previous CFM 56 engine.

1.4 Geared turbofan

Classic turbofan design incorporates high pressure shaft and low-pressure shaft to which the fan is connected, therefore the fan and low-pressure turbine with compressor must operate at same revolutions per minute (rpm). Given the larger diameter of the fan, speed on the tips of the fan blades is substantially higher than the speed of rotors in the turbine, creating strong centrifugal force and excessive noise when the fan tips break the sound barrier. For these reasons, low pressure turbine has additional stages which slow down the fan to around 3000 RPM. In consequence, the low-pressure shaft cannot rotate at optimal operating speed. With the general trend towards higher bypass engines, the size difference between fan and low-pressure turbine requires further reduction of low-pressure shaft RPMs to maintain reasonable speed at the fan tips. Large turbofans often use third shaft to power the fan from a separate turbine and allow the low-pressure compressor and turbine, which is in this configuration called intermediate pressure compressor and turbine, to run closer to its optimal speed.

By adding planetary gearbox between the fan and the low-pressure shaft, geared turbofan allows each component to run at its optimal speed and reduces the need for additional lp compressor and turbine stages. The idea of using gearbox in a jet engine was initially exploited in the 2nd half of 20th century with first production engine – the Garrett TFE 731-2 in use from 1972. Pratt & Whitney PW1000G turbofan engine is the newest production iteration of the concept. Gear reduction of three to one allows the fan to run much slower than the rest of the lp shaft resulting in noise reduction of up to 75% (according to P&W) and the pressure acting on the fan blades is reduced by great extent. Same applies for the tensile strength requirement resulting in industry's first use of aluminium as the material of choice for fan blades. Eric Roegner, COO of Alcoa – Metal engineering company manufacturing the aluminium blades – mentioned that the main advantages of using alloys are its affordability and 2% aerodynamic efficiency improvement compared to carbon-fibre composites while maintaining lower weight than titanium, although this metal is still used in trailing edge for its resistance to water erosion. Implementation of the engine on Airbus A320 resulted in 16% reduction in fuel burn compared to the previous P&W offerings. According to Pratt & Whitney president Robert Leduc, this improvement was achieved mainly by the gearbox, leaving space for further improvement of 6-7% by upgrading the core, adapting similar technologies to those used in CFM's Leap engine which achieved its 15% fuel improvement solely by the advanced core and light materials.

2 Safety technology

Even Though aviation is one of the most technologically advanced industries, paradoxically it is also industry with very conservative approach to innovations driven by high safety requirements. Thanks to this, flying is one of the safest means of transport with decreasing trend in number of accidents, even though the volume of air transport is growing rapidly. Improving safety technology is still aviation's main objective despite the already high standards in all layers of the industry.

After 9/11, airports implemented more thorough passenger controls including baggage screening and any item which could be weaponized was banned from being taken on board. To minimize accidents caused by human error, pilots are trained on advanced flight simulators and airplanes are equipped with autopilots and technologies that alert pilots to potential problems. Weather threats were addressed and minimized by onboard weather radars able to detect certain types of turbulences and giving the pilots time to avoid storms. In the future, we will see further implementation of augmented reality and artificial intelligence into the cockpit, giving the pilot means to detect threats unseen to the human eye and guiding the flight as another co-pilot.

2.1 Ground Proximity Warning System

Before the adaption of modern technologies, controlled flight into terrain (CFIT) caused numerous fatal accidents. According to International Air Transport Association (IATA) (2021), CFIT refers to "accidents in which there was an in-flight collision with terrain, water, or obstacle, without indication of loss of control." In other words, the collision with terrain occurs due to human error rather than technical malfunction. Introduction of mandatory Ground Proximity Warning System (GPWS) in 1974 reduced the number of CFIT accidents. However, many of these accidents still occurred due to imperfections of the GRWS system. The mechanism behind GPWS relied on altitude calculation from signal waves transmitted by radio altimeter, which was positioned on the downside of the fuselage, able to track only the distance between the aircraft and the ground directly below it. For this reason, when an obstacle such as a mountain or a high building appeared in the flight path, the system was not able to warn the pilot of the approaching obstacle in time. Still, it was a major safety improvement as it also indicated excessive descent rate, improper configuration of landing gear or sudden deviation in ascent rate.

Enhanced version of GPWS or simply EGPWS was introduced in 1996. In comparison with its predecessor, the technological gap of 22 years brought many new functions. The system no longer relied solely on altimeter data but rather on exact position of the aircraft provided by GPS combined with incorporated detailed terrain database which includes man made objects. By tracking the flight path and calculating the trajectory of an aircraft the system estimates which terrain ripples could mean a potential threat to the aircraft. Profile of the terrain is displayed on a screen in the cockpit in shades of green, orange and red according to the distance from the trajectory and possible hazard.

The introduction of GPS and terrain database allowed to give a warning to the pilot with more advance, but most importantly enabled the pilot to spot potential danger laying in front of the aircraft, eliminating the main flaws of the previous versions. However, the system is still not flawless as the terrain database is often composed of various sources and includes inaccuracies which can be eliminated only by thorough observations of the current system, resulting in corrections and adjustments in the future updates.

2.2 Realtime runway sensors

After the number of CFIT accidents was successfully minimized, the focus could be shifted towards another issue. Challenging weather conditions are the most frequent cause of flight delays or cancellations as flying in snowstorms or strong winds is dangerous and often impossible. Even though each delay means extra expenses for the airline, damages to the aircraft or an accident, in the worst case, is not a risk worth taking. Still, many accidents happen. Complications occur mostly during take-off and landing due to wind gusts, fog or, most frequently, weather affected runway surface. Even though the weather cannot be controlled, some of the modern state-of-the-art technologies come very close.

More profound Runway surface monitoring will be obligatory on global scale starting on 4th November 2021 as a part of New Global Reporting Format (GRF) initiated by ICAO. In words of ICAO Deputy Regional Director Nika Meheza Manzi (2019), the goal is to adopt "common language between all actors of the system that is based on the impact on aeroplane performance of the runway surface condition." Implementation of GRF will require cooperation of states to achieve united reporting methodology which will ultimately translate into systematized Runway condition report (RCR) consisting of information regarding type of runway contamination for each third of the runway and presumed impact on the aircraft.

Wellington Airport was one of the first to adopt real time monitoring system connected to runway sensors in accordance with GRF. The system provided by Metservice is composed of nine sensors which are collecting information about temperature, moisture or ice conditions that are then transmitted to Integrated Operations Centre. In the future, it should even be possible to send the data straight to the cockpit. Runway inspection vehicles are also equipped with sensors to provide additional monitoring.

Figure 4: Runway sensor (Wellington Airport, 2020)

As the development of such system is demanding on both money and time and the deadline is slowly approaching, some companies have recourse to modifications of their already existing sensors. Finnish industry-leading company Vaisala, specialising in weather, environmental and industrial measurements developed MD30 Mobile Detector primarily for snowploughs, but it can be retrofitted to any other vehicle and its measuring capabilities meet the ICAO standards. Collected data about the type of surface contamination can be viewed in text form complemented by video for better judgement via a smartphone app. In comparison with sensors embedded in the runway surface which collect data all the time, MD30 relies on the presence of airport vehicles. However, its simplicity of installation and affordability combined with user friendly software environment may prove convenient to airports which are trying to satisfy GRF requirements in time.

Hopefully, normalization of runway monitoring will lead to reduction of the number of runway excursions and will achieve improved aviation safety similarly to ground proximity warning system which prevented many collisions with the ground over the years. With Internet of things being continuously incorporated into aviation, it is expected that runway condition tracking systems will be guiding pilots during landing and take-off and will become a standard part of the cockpit in the immediate future.

3 Internet of things

The Internet of things (Iot) can be described as a network of all objects which are able to exchange data between each other without human interaction. These devices equipped with sensors range from smart appliances which can be controlled via smartphone in our households to modern cars with automatic park assist. Iot devices are simply making our lives easier with automatization of daily tasks. Utilization of IoT for industry purposes is however much more complex than standard IoT usage, main difference being the amount of exchanged data and broader diversity of use.

In aviation industry, 500 Gb of data can be generated during a single flight and this number is increasing with implementation of new sensors. Even the previous generation of aircrafts had ability to collect data about engine operations, fuel consumption and much more, but had limits for its use. It was known that potential of the data is much greater. Nowadays with advanced big data analytics and ability to transfer data from on-board sensors to control tower mid-flight, IoT is slowly changing all sectors of the industry. Analysed data from onboard sensors can be used to improve fuel efficiency by optimizing engine performance for different phases of a flight, or to improve reliability of components by collecting data from high stress situations whereas databases containing wide range of information can select the most efficient flight route and suitable type of aircraft for the given route. Data analytics also improve customer service and efficiency of pre-flight and post-flight procedures.

Summarized, if used correctly, the wide spectrum of information collected by IoT devices have the capacity to extract better performance from current technology while also simplifying many operations and increasing profit of airlines. One of the biggest additional costs for airlines comes from flight delays and is estimated to be $8 billion a year according to Federal Aviation Administration. Unforeseen technical issue found during the final check before departure is still one of the frequent reasons for delay, even though precautionary measures and scheduled work contrives to prevent most of the failures.

3.1 Predictive maintenance

In the past, maintenance of an aircraft was done either reactively or preventively. As the industry evolved, new technologies were brought to market at such rate that it was impossible to collect needed experience to accurately predict the lifetime of a component which resulted in maintenance often being performed too late, when a failure had already occurred. Airlines soon discovered that it was more beneficial to prevent these failures by replacing every component after a certain time in service, though it sometimes meant replacing a perfectly working component that could serve its function for a long time to come.

As stated by Boeing Regional Director Randy Heisei (2002), “depending on airplane age, type, and range, maintenance costs typically represent 10 to 20 percent of direct operating costs." This cost can now be significantly reduced by the application of predictive analytics which already proved useful in retail and marketing strategies. Predictive analytics use machine learning algorithms to find patterns in data regularly sent to cloud storage by sensors and similar devices. Such infrastructure requires considerable initial investment but should prove profitable in a long-term period. For example, if a sensor in a flying aircraft detects a problem, modern systems able to stream data in real time can evaluate the data while the aircraft is still airborne and by the time it lands, a technical support with detailed instructions can already be waiting at the airport. Since all the measuring devices can communicate with each other, it is possible to display an actual health of the whole fleet. Moreover, the accuracy of life cycle prediction and many other information will be strengthened as more data is recorded.

3.2 Prescriptive maintenance

Current shift from predictive towards prescriptive maintenance could not only reduce the time an aircraft is out of service, but also extend lifetime of various components. While predictive maintenance uses machine learning systems to identify data patterns for prognosis of potential component failure, prescriptive maintenance provides steps to follow for optimal solution of each problem. After analysing the collected data from a component, lifetime of the part is calculated. By then considering its significance, total time in operation and many other factors, the software evaluates consequences of the predicted failure as well as the optimal steps to prevent it. MRO survey carried out by Oliver Wyman in 2016 suggests that the global fleet could generate 98 million terabytes of data by 2026 (2016). Such big data capable of providing refinement in majority of operations is not processable by human brain or Excel sheets, therefore further development of IT is necessary.

Despite the numerous benefits prescriptive maintenance could provide to aviation sector, its implementation requires costly software changes and employment of skilled staff for system aftercare. Combined with alteration of regular maintenance processes required by Federal Aviation Administration (FAA) to satisfy all safety standards which would be needed to take full advantage of PM, global implementation still has a long way to go.

3.3 Drone inspection

Inspection of an aircraft is a mandatory procedure which is carried out by pilots before each flight to ensure the aircraft does not show any signs of damage on its exterior. According to Skybrary (2020), this type of inspection typically includes, amongst other tasks, control of brake wear indicators, tire condition, integrity of the fuselage and lookout for foreign objects. Pre-flight inspection is typically not too time-consuming and can be executed from the ground. However, inspections after bird collision or lightning strike where damage is expected can take up to 6 hours and demand use of heavy machinery to check for damage on the tail or the top of the fuselage.

In 2015, British low-cost airliner EasyJet pioneered the use of drones for aircraft inspection with great results. A quadcopter from Blue Bear Systems was programmed to follow a predefined flight path around an Airbus A320 and scan the airframe. Pictures taken by the drone are then evaluated by engineers. As EasyJet found that drone inspection can reduce the downtime of an aircraft by performing the inspections in fraction of time, many other companies soon followed in its steps. Airbus developed its own inspection drone under its company Testia, which is "specialised in Aerostructure inspections and integrity and Aerospace Non-destructive Testing" (Testia, 2020). In 30 minutes, the drone collects pictures of the aircraft which are then uploaded to inspection software which will recognize parts of aircraft that show signs of damage by comparing the pictures with database from previous inspections. Finally, the software concludes the inspection by creating an automatic report.

Although the drones are not yet standardized, it is an emerging market with high potential to become a norm in a near future. As such, companies are racing to offer the most effective and intuitive solution which can be sold as a complete packet to convince the airlines to invest into new technology. Mainblades is a Netherlands based company which specializes in developing inspection drones since 2017, but their initial idea goes back to 2013. According to the CEO, Dejan Borota (2020) the greatest challenge is to achieve global certification and conform to standard maintenance procedures, regulations, and safety requirements. To achieve this, Mainblades must find industry partners to leverage FAA (Federal Aviation Administration) and EASA (European Union Aviation Safety Agency) to easy the drone regulations in airport environment.

Their drone is compatible with any aircraft type and was recently updated to be operatable outside of controlled hangar environment by fulfilling IP67 waterproof standards. The flight path is fully automated including take-off and landing, and any instructed person can carry out the inspection as all needed equipment comes in one box including iPad with specialized application interface. Any irregularity found on the airframe is recorded in great details including the type of damage, its size and seriousness.

4 Future

With some new technologies already in their final stages of testing, many aspects of the usual aircraft concept will change in a near future. All forms of transport are continuously undergoing modernization and in the age of digital technology and electrification, aviation is no longer the pioneer of innovation as it once was.

While electrification is gaining momentum in automotive industry, introduction of battery technology suitable for aviation use is still some time away. However, digital technologies such as automation, in-flight connectivity or artificial intelligence are already present, and their influence will increase with intensified testing. Aviation is also expected to enter in-city transport sector. Dubai is currently planning sky corridors for drone taxis which are being tested in the city since 2017. For now, autonomous drones are limited to carrying cargo, but in the not-so-distant future, urban air mobility is expected to take off.

4.1 Transonic Truss-Braced Wing aircraft concept

Every aircraft is designed with the aim of improving its aerodynamics to reduce drag and even though some new aircraft concepts proved to be competitive in this regard, commercial aircraft manufacturers still stay loyal to the classic silhouette consisting of two wings, cylindrical fuselage, and conventional tail design. This uniformity across the commercial sector may implicate superiority of the said design, but as usual, the reality is more complicated.

Number of remarkable aircrafts was designed throughout the aviation history but solely fraction of them made it past the concept stage due to demanding certification process. To be convenient for mass production, aircraft design must be innovative enough to have benefits, but conservative enough to be usable with current airport infrastructure. Such challenging task may be accomplished by Boeing and their Transonic Truss-Braced Wing (TTBW) aircraft. Dating back to 2010 when Boeing joined forces with NASA on the Subsonic Ultra Green Aircraft Research (SUGAR), 4th iteration of the project is already being tested.

In current configuration, the aircraft saves 9% of fuel over conventional aircraft with similar fuselage size (Boeing 737). This was achieved primarily by implementing redesigned wings with large 51m wingspan which together with its thin design creates a very high aspect ratio. Before this project, similar wing design was used particularly for gliders with high bending stress preventing the use with larger and heavier aircrafts. To overcome this issue, the wing had to be made from advanced composite materials and brace connecting the middle of the wing with fuselage was added to provide additional structural support. Another innovative feature is the ability to fold the wings next to the brace – wing connection for better manœuverability on the ground. Folding wingtips were already tested on the Boeing 777x, but this design takes the technology one step further. In the air, manœuverability is also negatively affected by the large wingspan, but this does not present a handicap for long distance aircraft. Wings connected to the top of the fuselage also open the possibility to mount larger diameter engines under the wing which would further increase efficiency.

However, the wing design brings one major disadvantage. While wings of conventional aircraft are hollow and the whole structure is sealed to serve as integrated fuel storage, wings of TTBW aircraft are too thin to serve this purpose. Wet wing, as the wing fuel storage feature is called, offers efficient use of space, but the reasons behind its utilization are much more profound. Additional weight in the centre-positioned wings enhances centre of gravity and stabilises the aircraft, but also alleviates Aeroelastic flutter, a physical phenomenon creating unrestrained elastic motion fed by airflow which can cause a collapse of a structure. The lack of additional structural integrity provided by wet wing in combination with lighter composite construction and extended wingspan makes TTBW more prone to flutter. For these reasons, it is expected that next iteration of TTBW aircraft will include performance adaptive aeroelastic wing technologies such as the Variable Camber Continuous Trailing Edge Flap system.

Figure 4: Transonic Truss-Braced Wing aircraft concept (Boeing, 2019)

4.2 Supersonic flight

Since the grounding of Concorde in 2003, the option of supersonic commercial flights vanished, and the fastest operating aircrafts reached the speeds of 0.86 MACH (Speed of sound) which is still the case today. MACH speed was exceeded only two times in the history of commercial aviation and both aircrafts ended its service long time ago. Tupolev Tu-144, the Soviet supersonic aircraft entered service 2 months before Concorde in December of 1968 and was retired from commercial flights after 1 year due to safety issues and high operation costs. Similar problems were dealt with by Concorde which had slightly lower fuel burn due to the ability to fly above MACH speed without the use of afterburners. Unlike Tupolev, extensive testing was performed on Concorde to ensure safe operation. The interest of wealthy clientele made it possible to operate the aircraft for 27 years even though it burned 5x more fuel per passenger than standard commercial aircraft.

There were several major shortcomings which eventually led to its termination. Due to shock wave caused by breaking the sound barrier and associated loud noise resembling an explosion which is called the Sonic boom, the aircraft was banned from flying overland. It was also efficient only for long distances, so the number of feasible routes was very low and towards the end of its existence, there was only one regular flight from London to New York. Another setback was the accident in 2000 after which the number of loyal passengers dropped and together with higher maintenance costs after many years of service, further flights became unfeasible.

4.2.1 Aerion AS2 supersonic jet

Today, after a long break and over 50 years from first supersonic commercial flights, the idea is slowly coming back to life. First new age supersonic flight initiative appeared in 2002 under the name Aerion Supersonic. The company have not released a complete aircraft yet, but with completed wind tunnel testing in December 2020 and manufacturing plant under construction, its AS2 concept seems to be close to production. AS2 employs delta wing shape like Concorde but with 6-10 passenger capacity, AS2 aims at private jet market. If we go a bit further in the comparison with Concorde, we can see that the cruise speed of AS2 is supposed to be considerably lower at 1715 km/h vs 2200 km/h, but Aerion attributes more importance to sustainability and comfort of the passengers. According to Tom Vice, CEO of Aerion Supersonic, AS2 will provide carbon neutral operation from first flight scheduled in 2027 thanks to compatibility with 100% synthetic fuel. Although there is currently no indication that the ban on overland supersonic flights will be cancelled, AS2 can combine subsonic speed over highly populated areas or areas where supersonic flights are banned with supersonic speed over unpopulated areas or water surface in one flight. Aerion uses proprietary Boomless cruise technologies to repulse the sonic boom sound effect in the denser layer of the atmosphere. The Affinity supersonic engines are provided by GE aviation. While Netjets, the foremost business jet operator ordered 20 AS2 jets, Aerion is already working on even more futuristic concept, the AS3. This aircraft should be the answer to supersonic commercial flights with space to comfortably transport 50 passengers at speeds exceeding MACH 4. In words of Tom Vice, Aerion plans to make any place on the planet reachable within 3 hours.

Unfortunately, as of 22nd May 2021, Aerion Supersonic shut down due to a lack of funding. Although the company worked with industry giants such as Boeing and GE, it was unable to secure 4 billion dollars needed to produce the AS2.

4.2.2 Boom Overture supersonic jet

Funded by 27 investors (the latest being American Express Ventures) and with pre-orders totalling at 6 billion dollars, Boom Supersonic is another company seemingly close to production of a supersonic jet. On 7th October 2020, Boom publicly presented 1/3 scale demonstrator model of their Venture supersonic airliner, the XB – 1 nicknamed Baby Boom. This functional model equipped with 3 GE Aviation J85-15 afterburner turbojets (also used on US Army jets) will serve as a technology testing platform for the Overture and its first flight is planned for 2021, although postponement till the next year is possible. Nonetheless, it is the first civil supersonic jet built by a start-up company without government funding. According to the founder Blake Scholl (parafráze – rok?), unlike the XB – 1, Overture will use yet unspecified engines without afterburners, presumably produced by long time partner, Rolls Royce. He further mentioned that Venture will have comparable fuel efficiency to current subsonic aircrafts and run on SAF. An important factor in Boom's marketing is the ticket pricing which should be on par with current business class ticket fares. With capacity for up to 75 passengers in business configuration and cruising speed of MACH 2.2, Venture plans to offer commercial supersonic flights by 2029.

4.3 Electric propulsion

In response to rising environmental concerns, aviation became the first industry sector to introduce global long-term plan for cutting emissions in 2009. Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) implemented by Civil Aviation Organization (ICAO) set a goal of 50% reduction in global emissions by 2050 respective to 2005 level which also encouraged faster development of green technologies. Although this goal is achievable, it will push current technology close to its limits and further improvements will become inefficient. After this stage is reached, focus of developers will shift towards more radical solutions with greater potential such as electric propulsion. Use of electricity is the solely path to decarbonize flights if all electricity is generated from sustainable sources. Hence the industry will have to invest in green energy to achieve better results.

The idea of electric aircraft is already under investigation of many companies with over 200 concepts in development such as Eviation Alice, NASA's X57, E-Fan X by Airbus or Magni500 propulsion system by MagniX, a company with specialization in electric engines. Although MagniX is not producing complete aircraft, their systems can be retrofitted into existing airframes. In collaboration with AeroTec, ECaravan, the largest functional all-electric aircraft potentially capable of transporting 9 passengers was produced and already completed its maiden flight on 28th May 2020. However, in current configuration Ecaravan can carry 4 – 5 with 160 km flight range. Companies behind the project suggest that certification of the aircraft could be possible in 2021 and by then it should be capable of carrying the full load of 9 passengers over the same distance. In the future, aircrafts powered by MagniX motors could become more feasible alternative to fuel powered aircrafts for regional flights as the cost of electricity required for half hour flight is 6 dollars whereas fuel cost would exceed 300 dollars.

The biggest drawback of electric propulsion is the limited flight range due to the weight of current batteries. Even the most advanced battery provides insufficient power to weight ratio to propel larger aircraft over longer distance. Although solar powered aircraft from Solar Impulse completed around the world flight in 2013, it is not feasible for commercial use as it is able to accommodate just the pilot. In addition, the batteries are subject to degradation with repeated charging cycles requiring expensive battery change after its capacity is insufficient and the time needed to charge the batteries means prolonged ground time between flights. The batteries in question are based on Lithium – ion cells. This type of battery is used in smartphones, but also electric cars and now electric planes for its unbeaten characteristics. However, the technology introduced in 2nd half of 20th century has matured and additional improvements are hard to reach. The most powerful batteries suitable for transport usage produce around 165 Wh/kg while electric aircrafts would need 500 Wh/kg to have comparable properties to jet planes.

Joining forces with automotive industry could provide benefits as leaders of car electrification such as Tesla or GM promise to introduce more powerful batteries to market in a near future. Also, new methods of battery production with the potential to outperform Lithium – ion batteries are emerging. Battery design from IBM research promises new battery chemistry free of heavy metals with reduced environmental impact and the ability to charge faster while providing higher energy density. Low flammability of the battery makes it suitable for aviation use, although the research is primarily aimed at electromobility. Until similar technology is brought to market, electric aircrafts have very limited use.

Conclusion

Even though flight evolved long before mankind, for centuries it stayed something people could have only dreamt about. Yet only 120 years from the creation of the first airplane, flying is nowadays part of our lives which makes aviation one of the most progressive industry sectors. Behind this rapid expansion are many cutting edge technologies, often sprawling across the borders of aerospace into other spheres. This thesis ventured into the realms of sustainability, safety, and maintenance to present some of the recent technologies from these fields to the reader and outlined potential direction of future development. Green technologies were given more space throughout the work since their implementation is crucial for the future of aviation and our planet while the chapter comprising the theme of aviation safety is planned to be expanded in the bachelor thesis.

Despite the enormous advancements in technology, the last truly radical evolution of aviation happened in the War era when governments invested in warplane production to gain technological advantage. Intervention of the government with the aviation sector lessened after the World Wars but as the world jumps into next, imaginary war with climate changes, the need to accelerate the boarding of green technology into production to lower the environmental impact of aviation may involve the government once again.

EXTENDED ABSTRACT IN CZECH LANGUAGE

Tato bakalářská práce se zaměřuje na popis aktuálních technologií a trendů v různých oblastech leteckého průmyslu. Velký důraz je přikládán technologiím, které snižují dopad na životní prostředí, ale také těm, které zvyšují bezpečnost letectví a usnadňují údržbu. Závěrečná kapitola se zabývá technologiemi v různých fázích vývoje a koncepty, které mají reálný potenciál změnit tvář leteckého průmyslu tak, jak jej známe.

Letecký průmysl byl od svého vzniku na počátku 20. století průkopníkem nových technologií, které často našly využití i v jiných odvětvích. Bratři Wrightové odstartovali roku 1903 prvním letem ve svém kluzáku hon za dobitím oblak. Následoval bleskový vývoj technologií, a zanedlouho začaly vznikat první letecké společnosti přepravující zákazníky po celém světě. Tento rozmach letectví je přičítán hlavně ikonickým letounům jako byl Douglas DC-3 které ujistily pasažéry svou spolehlivostí a poskytly jim komfort na dlouhých trasách. Po éře válečných inovací se s představením proudového motoru v 50. letech silueta dopravního letounu ustálila, a letectví začalo být čím dál více přístupné i pro širší veřejnost.

V dnešní době je největším tématem letectví, stejně jako i jiných odvětví průmyslu, dopad na životní prostředí a s tím spojené snižování emisí. I když se letectví na celkové produkci skleníkových plynů podílí zdánlivě nízkými 2,1 %, v pomyslném žebříčku meziročního růstu emisí je letecká doprava na prvním místě. Z tohoto důvodu představila Mezinárodní organizace pro civilní letectví (ICAO) v roce 2009 dlouhodobý plán pro snížení emisí, které by, oproti hodnotám z roku 2005, měly do roku 2050 klesnout o 50 %. Splnění tohoto požadavku bude vyžadovat implementaci nových technologií jako je například 3D tisk, který snižuje váhu komplexních komponentů a zároveň šetří materiál během výrobního procesu. Společnost GE Aviation si osvojila tento výrobní proces již v roce 2015 a vytvořila první velkokapacitní výrobnu 3D komponentů v leteckém průmyslu. I díky tomu je jejich motor LEAP výrazně lehčí ve srovnání s konkurencí. Tento motor dosáhl skvělých výsledků například na letounu Boeing 737 MAX, u kterého snížil spotřebu paliva o 15 % a hladinu hluku o 75 %. Konkurence v podobě motoru PW1000G společnosti Pratt&Whitney použila k dosažení obdobných výsledků zcela odlišnou technologii. Využitím planetárního převodu bylo docíleno pomalejší rotace větráku, zatímco ostatní komponenty motoru mohou nadále pracovat v pro ně optimálních otáčkách. Dle vedení firmy nechává tato technologie prostor pro další snížení spotřeby, a to až o 7 %.

I když jsou tato čísla na poměry letectví obrovskými kroky vpřed, splnění cílů vytyčených organizací ICAO vyžaduje radikálnější řešení jako například využití paliva z obnovitelných zdrojů. Kamenem úrazu je nekompatibilnost aktuálně vyráběných letadel se 100 % přírodními palivy, kvůli čemuž je povolené pouze mixování klasického paliva s biopalivem tak, aby zůstaly zachovány vlastnosti petroleje.

I přes snahu normalizovat velké množství nových technologií je zvyšování bezpečnosti stále prioritou číslo jedna. Pilot má dnes k dispozici mnoho pomocných technologií, které mají za úkol předcházet selhání lidského faktoru které v minulosti způsobilo mnoho kolizí s terénem. Dnes už je každé letadlo povinně vybaveno systémem, který kontroluje výšku letu a zavčas upozorní na případné nebezpečí. K většině leteckých nehod dochází těsně po odletu nebo při přistávání, častým důvodem zde bývá zhoršená viditelnost či změna fyzikálních vlastností povrchu přistávací dráhy způsobená počasím, kvůli čemuž letadlo nestihne zavčas zabrzdit. Četnost těchto nehod přiměla ICAO k zavedení uniformního systému nahlašování kontaminace ranveje, který má vstoupit v platnost 4. listopadu 2021. Letiště ve Wellingtonu se na zavedení tohoto systému předpřipravilo instalací 9 senzorů do povrchu ranveje které za pomoci programu vyhodnocují stav povrchu. V budoucnu by tyto informace mohly být promítány přímo do kokpitu a pomáhat tak pilotům lépe vyhodnocovat přistávací manévry.

Podobná síťová propojení přístrojů mohou být hromadně označena pojmem Internet věcí. Sdílení dat mezi přístroji bez potřeby lidské interakce je využitelné i při prediktivní údržbě letadel která využívá shromažďování velkého množství dat v cloudovém úložišti. Speciální program za pomoci strojového učení v datech nachází vzory, ze kterých je pak schopen vyvodit životnost komponentu a výrazně tím snížit náklady za opravu. Dalším krokem je preskriptivní analýza dat, která dokáže díky databázi vyhodnotit nejvhodnější postup pro opravu daného komponentu. Inspekce letadel by se pak mohly dočkat automatizace za pomoci dronů. V roce 2013 byla tato technologie poprvé využita společností Easyjet při inspekci Airbusu A320. Předdefinovaná dráha letu zajistila automatické naskenování trupu letadla a fotografie nahrané do počítače pomohly odhalit nedokonalosti na povrchu letadla. Potenciál této technologie výrazně zkrátit dobu kontrol však zatím brzdí regulace používání dronů v letištním prostředí.

Pokročilé materiály jako jsou uhlíkové kompozity dnes umožňují jiné výrobní techniky, než tomu bylo dřív. V blízké budoucnosti se díky těmto materiálům můžeme dočkat kompletně změněné podoby letadla. Boeing sází na koncept s ultratenkými křídly, který se nejvíc podobá kluzáku, a oproti klasickému tvaru letadel je velmi aerodynamický. Jiní výrobci jako Aerion nebo Boom Supersonic sází na komerční nadzvukové lety, které vymizely se zánikem Concordu v roce 2003. Společnost Boom vyvíjí letoun pro 75 pasažérů, který by měl vzlétnout do oblak v roce 2029. Nadzvukové lety by se tak mohly stát opět realitou, a to za použití biopaliva.

V době, kdy rapidně vzkvétá elektromobilový průmysl, se naskýtá otázka, proč nedochází k elektrifikaci i v letectví. Touto problematikou se aktuálně zabývá více než 200 různých společností, ale kvůli vysoké hmotnosti baterií je řešení zatím v nedohlednu. Pár letadel s čistě elektrickým pohonem už sice vzlétlo, ale pro potřeby komerčního letectví jsou tyto prototypy zatím nepoužitelné. I kvůli potřebám elektromobility se však do vývoje baterií hojně investuje, a technologie slibující kapacitu baterií vhodnou pro letecké využití se tak mohou již brzy stát realitou.

REFERENCES

3D Printing Media Network. *GE Reveals How Greg Morris Created the 3D Printed Nozzle for the LEAP Jet Engine*. 2017. Retrieved from: https://www.3dprintingmedia.network/ge-reveals-greg-morris-created-3d-printed-nozzleleap-jet-engine/

3DPrinting. *What is 3D Printing?* N. d. Retrieved from: https://3dprinting.com/what-is3d-printing/

Airbus. *Airbus launches advanced indoor inspection drone*. 2018. Retrieved from: https://www.airbus.com/newsroom/press-releases/en/2018/04/airbus-launches-advanced-indoor-inspection-drone-to-reduce-aircr.html

BAILEY, Joanna. *How Many DC-3 Are Still Flying?* 2020. Retrieved from: https://simpleflying.com/dc-3-operation/

BAILEY, Joanna. The Boeing TTBW – The Future Of Passenger Planes? 2020. Retrieved from: https://simpleflying.com/boeing-ttbw/

BANKE, Jim. *NextGen Aircraft Design is Key to Aviation Sustainability*. NASA. 2020. Retrieved from: https://www.nasa.gov/aero/nextgen-aircraft-design-is-key-to-aviationsustainability

BENNINGFIELD, Damond. *Ground Proximity Warnings*. 2003. Retrieved from: https://www.airspacemag.com/how-things-work/ground-proximity-warnings-4244883/

BJERREGAARD, Lindsay. *New Player Enters The Aircraft Drone Inspection Market*. 2021. Retrieved from: https://aviationweek.com/mro/emerging-technologies/new-player-enters-aircraft-drone-inspection-market

Bluebird Marine Systems Limited. *The Schneider Trophy*. 2014. Retrieved from: https://www.bluebird-electric.net/schneider_trophy.htm BOYNE, Walter James. *History of flight*. 2006. Retrieved from: https://www.britannica.com/technology/history-of-flight

BOROTA, Dejan In *Mainblades' Autonomous Drone Is Designed to Efficiently Inspect Manned Aircraft*. 2020. Retrieved from: https://www.commercialuavnews.com/infrastructure/mainblades-autonomous-drone-is-designed-to-efficiently-inspect-manned-aircraft

BOTTOMLEY, Victoria. *Why Airplanes Store Fuel in the Wings (wet wings)*. 2020. Retrieved from: https://www.aircraftcompare.com/blog/airplanes-fuel-wet-wings/ NAMES, Ben. *5 Things You Should Know About Flutter*. 2020. Retrieved from: https://structures.aero/blog/5-things-should-know-flutter/

BOYLE, Alan. *MagniX and AeroTEC put all-electric Cessna airplane into the air for first time*. 2020. Retrieved from: https://www.geekwire.com/2020/magnix-aerotec-cessna/

BOYNE, Walter James. *Propulsion systems*. 2003. Retrieved from: https://www.britannica.com/technology/airplane/Propulsion-systems

BRITANNICA, The Editors of Encyclopaedia. *Concorde*. 2020. Retrieved from: https://www.britannica.com/technology/Concorde

BROTHERS, Eric. *Prescriptive analytics in aircraft maintenance*. 2017. Retrieved from: https://www.aerospacemanufacturinganddesign.com/article/prescriptive-analytics-inaircraft-maintenance/

BROTHERS, Eric. *American Express Ventures invests in Boom Supersonic*. 2021. Retrieved from: https://www.aerospacemanufacturinganddesign.com/article/american-express-ventures-invests-boom-supersonic/

BURGESS, Matt. *What is the Internet of Things?* 2018. Retrieved from: https://www.wired.co.uk/article/internet-of-things-what-is-explained-iot DENIS, Michael Wm. *The Internet of Flying Things: Part 1*. 2015. Retrieved from: https://www.aircraftit.com/articles/the-internet-of-flying-things-part-1/

BURKE, Kathleen. *How the DC-3 Revolutionized Air Travel*. 2013. Retrieved from: https://www.smithsonianmag.com/history/how-the-dc-3-revolutionized-air-travel-5444300/?no-ist

CHANDLER, J. G. *Taking the LEAP: CFM's Successor to the Fabulous 56*. 2017. Retrieved from: https://www.aviationpros.com/engines-components/aircraftengines/turbine-engines-parts/article/12328944/taking-the-leap-cfms-successor-to-thefabulous-56

CRITTENDEN, Mark. *With Ultralight Lithium-Sulfur Batteries, Electric Airplanes Could Finally Take Off*. 2020. Retrieved from: https://spectrum.ieee.org/aerospace/aviation/with-ultralight-lithiumsulfur-batterieselectric-airplanes-could-finally-take-off

CUMMINS, Nicholas. The Airbus A380 vs Boeing 747 – Which Plane Is Best? 2020. Retrieved from: https://simpleflying.com/a380-vs-747/

DAVIES, Ross. *REAL-TIME RUNWAY MONITORING: ICAO'S NEW GLOBAL REPORTING STANDARD*. 2020. Retrieved from: https://airport.nridigital.com/air_may20/airport_runway_monitoring

DEAL, Kevin. *Airlines and MRO to benefit from IoT, prescriptive maintenance, augmented reality in 2017*. 2017. Retrieved from: https://www.intelligentaerospace.com/commercial/article/16544560/airlines-and-mro-to-benefit-from-iotprescriptive-maintenance-augmented-reality-in-2017

DENIS, Michael Wm. *The Internet of Flying Things: Part 2*. 2015. Retrieved from: https://www.aircraftit.com/articles/the-internet-of-flying-things-part-2/

DILBA, Denis. *Geared Turbofan: How the engine of the future was developed*. 2019. Retrieved from: https://aeroreport.de/en/innovation/geared-turbofan-how-the-engine-of-the-future-was-developed

DUBOIS, Thierry. *Pratt, Alcoa Pioneer Use of Aluminum Fan Blades*. 2014. Retrieved from: https://www.ainonline.com/aviation-news/air-transport/2014-07-28/pratt-alcoa-pioneer-use-aluminum-fan-blades

GE. *Additive manufacturing*. N. d. Retrieved from: https://www.ge.com/additive/additivemanufacturing/industries/aviation-aerospace

HADER, Manfred and Stephan BAUR. *Cargo drones: The future of parcel delivery*. 2020. Retrieved from: https://www.rolandberger.com/en/Insights/Publications/Cargodrones-The-future-of-parcel-delivery.html

HEISEI, Randy. *Aeromagazine*. 2018, (19). Retrieved from: http://www.boeing.com/commercial/aeromagazine/aero_19/717_story.html#:~:text=Maintenance%20costs%20are%20a%20significant,to%2020%20percent%20of%20DOC

IATA. *Controlled Flight Into Terrain (CFIT)*. 2021. Retrieved from: https://www.iata.org/en/programs/safety/controlled-flight-into-terrain/

ICAO. *Future of Aviation*. N. d. Retrieved from: https://www.icao.int/Meetings/FutureOfAviation/Pages/default.aspx

ICAO. *In-sector aviation CO2 emissions reduction initiatives - Tracker tool.* N. d. Retrieved from: https://www.icao.int/environmentalprotection/SAC/Pages/Technology.aspx

KOMMENDA, Niko. How your flight emits as much CO2 as many people do in a year. 2019 Retrieved from: https://www.theguardian.com/environment/nginteractive/2019/jul/19/carbon-calculator-how-taking-one-flight-emits-as-much-as-manypeople-do-in-a-year

MANZI, Nika Meheza. *Global methodology for assessing and reporting runway surface conditions (GRF)*. 2019. Retrieved from: https://www.icao.int/WACAF/Documents/Meetings/2019/ICAO-ACI-Implemnetation%20runways/1.%20Overview.pdf

MARINESCU, Dan. *The XB-1 Is a Supersonic Jet on a Flight Path to the History Books*. 2021. Retrieved from: https://www.autoevolution.com/news/the-xb-1-is-a-supersonic-jet-on-a-flight-path-to-the-history-books-161537.html

Mototok. *HOW AVIATION CAN PROFIT FROM PREDICTIVE MAINTENANCE*. 2019. Retrieved from: https://www.mototok.com/blog/predictive-aviation-maintenance

Munich airport. *Green light for sustainable fuels.* 2021. Retrieved from: https://www.munich-airport.com/press-green-light-for-sustainable-fuels-11068785

NA, Young-hye. *Free of Heavy Metals, New Battery Design Could Alleviate Environmental Concerns*. 2019. Retrieved from: https://www.ibm.com/blogs/research/2019/12/heavy-metal-free-battery/

NAPERT, Greg. *Fuel Nozzle Inspection*. 2020. Retrieved from: https://www.aviationpros.com/home/article/10388587/fuel-nozzle-inspection

OVERTON, Jeff. *Fact Sheet: The Growth in Greenhouse Gas Emissions from Commercial Aviation.* EESI. 2019. Retrieved from: https://www.eesi.org/papers/view/fact-sheet-the-growth-in-greenhouse-gas-emissionsfrom-commercial-aviation

Paris H, et al. Comparative environmental impacts of additive and subtractive manufacturing technologies. CIRP Annals - Manufacturing Technology. 2016. Retrieved from: http://dx.doi.org/10.1016/j.cirp.2016.04.036

PLATT, Craig. *Aerion Supersonic AS2...* 2021. Retrieved from: https://www.traveller.com.au/aerion-supersonic-as2-new-supersonic-jet-undergoes-testing-as-giant-manufacturing-plant-unveiled-h1tm9n

RAMADAN, Louise. *Ground Proximity Warning System (GPWS): How does it work?* 2021. Retrieved from: https://theaviationbase.com/ground-proximity-warning-system-gpws/

ROSS, Philip E. *Boom Supersonic's XB-1 Test Aircraft...* 2021. Retrieved from: https://spectrum.ieee.org/aerospace/aviation/boom-supersonics-xb-1-test-aircraft-promises-a-new-era-of-faster-than-sound-travel

SCHEELHAASE, Janina. Synthetic fuels in aviation – Current barriers and potential political measures. 2019. Retrieved from: https://www.sciencedirect.com/science/article/pii/S2352146519305824 RAND. *Near-Term Feasibility of Alternative Jet Fuels*. 2009. Retrieved from: https://www.rand.org/content/dam/rand/pubs/technical_reports/2009/RAND_TR554.pdf HALL, Nancy. *Beginner's Guide to Propulsion.* NASA. 2015. Retrieved from: https://www.grc.nasa.gov/www/k-12/airplane/bgp.html

SCHONLAND, Addison. *CFM LEAP vs P&W GTF*. 2020. Retrieved from: https://airinsight.com/cfm-leap-vs-pw-gtf/

SHEETZ, Michael. *Jet builder Aerion expects to fly silent supersonic planes by 2024* [online]. 2020. Dostupné z: https://www.cnbc.com/2020/01/16/aerions-as2-silent-supersonic-jet-aims-to-fly-by-2024.html?fbclid=IwAR1f9vjHisrz0Ncoq7ag-OSlBhE7L89a2ADi2pUbgd3MMNhKN_1EFx_J6GQ

Skybrary. *Flight Crew Pre Flight External Check*. 2020. Retrieved from: https://www.skybrary.aero/index.php/Flight_Crew_Pre_Flight_External_Check#Content_and_Conduct

Skytanking. Aviation Fuels: Jet Fuel, Aviation Gasoline (Avgas), Jet B, Biokerosene. 2015. Retrieved from: https://www.skytanking.com/en/newsinfo/glossary/details/term/aviation-fuels-jet-fuel-aviation-gasoline-avgas-jet-bbiokerosene.html

Smithosian National Air and Space Museum. *The Wright Brothers*. N. d. Retrieved from: https://airandspace.si.edu/exhibitions/wright-brothers/online/

STEINEGGER, Rolf. Fuel Economy as Function of Weight and Distance. 2017. Retrieved from:

https://digitalcollection.zhaw.ch/bitstream/11475/1896/6/Steinegger_Fuel_Economy_as_a_Function_of_Weight_and_Distance_v1-1.pdf

Testia. *About us*. 2020. Retrieved from: https://www.testia.com/about-us/

The Associated Press. *Flight delays are costing airlines serious money*. 2014. Retrieved from: https://mashable.com/2014/12/10/cost-of-delayed-flights/?europe=true

THOMSON, Robert. The number of electrically propelled aircraft developments grew by *~30% in 2019*. 2020. Retrieved from: https://www.rolandberger.com/en/Point-of-

TING, E.; REYNOLDS, K.; NGUYEN, N. and TOTAH, J. Aerodynamic Analysis of the Truss-Braced Wing Aircraft Using Vortex-Lattice Superposition Approach. N. d. Retrieved from:
https://ntrs.nasa.gov/api/citations/20140011160/downloads/20140011160.pdf

TYRRELL, Michael. *A quantum leap forward*. 2017. Retrieved from:
https://www.aeromag.com/cfm-international-leap-engine-high-bypass-turbofan-engine/

Vaisala. *Vaisala Mobile Detector MD30*. 2020. Retrieved from:
https://www.vaisala.com/sites/default/files/documents/MD30-ProductSpotlight-210x280-B211809EN-C.pdf

VERDON, Michael. *Supersonic Jet Maker Aerion Shuts Down*. 2021. Retrieved from:
https://robbreport.com/motors/marine/aerion-shuts-down-1234615163/

VERGER, Rob. *NASA's weird wing design could lead to futuristic, fuel-efficient airplanes*. 2020. Retrieved from: https://www.popsci.com/story/technology/nasa-boeingtruss-braced-wing-airplane/

View/Electric-propulsion-is-finally-on-the-map.html

Wellington Airport. *WELLINGTON AIRPORT FIRST IN SOUTHERN HEMISPHERE TO INSTALL REAL-TIME RUNWAY MONITORING SYSTEM*. 2020. Retrieved from:
https://www.wellingtonairport.co.nz/news/airport-updates/wellington-airport-first-install-real-time-runway-monitoring-system/

WORMSLEV, Erik C. and BROBERG, Mathilde K. *Sustainable Jet Fuel for Aviation*. Niras A/S. 2020. Retrieved from:
https://www.nordicenergy.org/wpcontent/uploads/2020/02/Sustainable-Jet-Fuel-Update-FinalNER.pdf

WYMAN, Oliver. *MRO SURVEY 2016*. 2016. Retrieved from: https://www.oliverwyman.com/our-expertise/insights/2016/apr/mro-survey-2016.html#:~:text=We%20estimate%20that%20the%20global,are%20cared%20for%20and%20perform.

YOUNG, Chris. *Boom Supersonic Is Set to Launch the Concorde's Spiritual Heir*. 2021. Retrieved from: https://interestingengineering.com/boom-supersonic-plans-to-launch-the-concordes-spiritual-heir

ZORIY, Viktoriya. *EASYJET MAKES DRONE INSPECTION A REALITY IN AVIATION MRO*. 2020. Retrieved from: https://mainblades.com/article/easyjet-makes-drone-inspection-a-reality-in-aviation-mro/